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Seasonal and spatial variations of heavy metals in water and sediments from mainland and maritime areas of Ebrie lagoon (Côte d'Ivoire, Western Africa)

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ABSTRACT

This study has been conducted to assessment the contamination level of the water and sediment by heavy metals of the both mainland and maritime areas in western part of Ebrie lagoon. Water and sediments samples were collected in eleven stations in mainland and maritime areas from February 2014 to January 2015. Water quality parameters such as temperature, pH, conductivity, transparency, salinity and dissolved oxygen were measured in situ and suspended matter in a laboratory. The concentration levels of mercury (Hg), lead (Pb), Cadmium (Cd) and Arsenic (As) in water and sediments were determined using Atomic Absorption Spectrophotometer. The results showed that seasonal mean values of heavy metals varied slightly during the dry, rainy and swelling seasons in both the maritime and mainland areas. The highest average values of heavy metals were recorded in the mainland area. Seasonal concentration levels of mercury and cadmium in the both maritime and mainland areas were above the safe limit for human consumption. The Pearson correlation between heavy metals and physico-chemical parameters showed a relationship between these parameters. The contamination factor (CF) in mainland and maritime areas showed that the sediments were moderately contaminated for Hg, Pb, and Cd and As during all seasons, except Cd in maritime area. Maritime sediment is low contamination for Cd. The PLI value (PLI>1) indicates polluted sediment from mainland and maritime areas. However, generally, the mainland area is more polluted.

Keywords: Physico-chemical parameters, exchange factor, contamination factor, pollution load index.

INTRODUCTION

The contamination of freshwater bodies with a wide range of pollutants has become a great concern over the last few decades. Heavy metals are natural trace elements of the aquatic environment, but their levels have increased due to industrial, mining, domestic and agricultural activities (Kalay and Canli, 2000; Callender, 2003). Metals may enter aquatic systems from different natural and anthropogenic (human activities) sources which may include

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industrial or domestic wastewater, application of pesticides and inorganic fertilizers, storm runoff, leaching from landfills, shipping and harbour activities, geological weathering of the earth crust and atmospheric deposition (Yilmaz, 2009).

In Côte d'Ivoire the lagoon system is influenced by anthropogenic activities which are practiced around. The urban and agriculture practices, waste water, industrial activities contributed highly to the degradation of the lagoon. Also the changes observed in the lagoon environment are associated with the influence of the freshwater and oceanic water. Heavy metals are concentrated in areas where the populations are dense (Scheren et al., 2004; Soro et al., 2009; Yao et al.,2009; Mondé et al., 2011; Coulibaly et al., 2012; Koffi *et* al., 2014; N'guessan, 2014; Inza et al., 2015; Gouin et al., 2016)**.** These studies revealed that in Africa, especially in Côte d'Ivoire, lagoon environment is generally the outlet of pollution. In the western part of the Ebrie lagoon, near the cities of Jacqueville and Dabou, where several human activities are taking place, pollutions are more frequent. In mainland area, agricultural activities (local plantations of banana and coconut), fishing activities, industrial activities were much practiced. Also, this area is influenced by Agneby, Comoe and Me rivers flow. In the other hand, activities such as washing, fishing, tourism and restaurant were practiced in the maritime area.

According to Sarma et al. (2011), these activities are the main sources of heavy metals pollution in aquatic ecosystems. Thus, heavy metals pollutions lead to the destruction of habitat, thus serious ecological threats and impact the quality of various resources (Villanueva, 2004; Coulibaly et al., 2010). After discharge into the ecosystem, these pollutants can stay in the dissolved form or be removed from the water column through sedimentation (Oliveira Ribeiro et al., 2002). Some metals such as lead, cadmium, mercury and arsenic as major pollutants because of their toxicity. Moreover, they are persistent and tend to bioaccumulate in the food chain posing a risk to humans and ecosystems (EPA, 2009). Pollution can impair the use of water and can create hazards to public health through toxicity or the spread of diseases. Owing to their toxicity and cumulative effect, discharge of heavy metals into the aquatic environments can alter the diversity of aquatic species and ecosystems. Since October 1999, massive mortalities of fish have been observed in the part of Ebrie lagoon, located near the cities of Jacqueville and Dabou. In May 2013, the high mortality occurred in this part of the Ebrie lagoon led to the closure of the fishing and aquaculture farms. However, no research on pollution has been done in the area.

The aim of this study was to monitor the levels of metals – mercury (Hg), cadmium (Cd), lead (Pb), Arsenic (As) in the water and the sediments of the maritime and continental western Ebrie lagoon areas and assess the influence of the human activities.

MATERIALS AND METHODS

Water and sediment sampling and analysis

All samples of sediments and water were collected monthly from February 2014 to January 2015 in the maritime and mainland areas in the west of Ebrie lagoon (05°16'N-04°15 – 4°30 W) near the cities of Jacqueville and Dabou. The sites were selected based on a number of factors, including the anthropogenic activities and massive mortalities of fishes. Indeed, several activities such as agriculture, fishing were practiced in the areas. Thus, water and sediments samples were collected fromthe stations of Layo, Songon, Papoga, Mopoyem, Gboubo, and Abraco in the mainland area, and Ahua, Bapo, N'djem, Koko, Taboth in the maritime area (Figure 1). At each sampling site, water sample was collected using Niskin bottle about 0.5m deep. Water samples were filtered through a 200 µm micropore membrane filter and were kept in polyethylene bottles and transported to the laboratory within one hour of collection and kept in the refrigerator until ready for heavy metals analyses. Sediments were sampled using a bucket Van Veen (0.05 m^2) at the sediment-water interface and collected in aluminium foil paper, thoroughly mixed and stored in labelled black polythene bags for laboratory analysis. Sediment samples were air dried for about five days; ground using a silica pestle and agate mortar and sieved through a <63 µm mesh sieve. The fine powder samples were dried again at 60 °C until obtaining constant weight. Then sediments samples were stored in polyethylene bags by the addition of nitric acid at 10% and were kept at 4 °C until analysis.

Mercury (Hg), lead (Pb), cadmium (Cd) and arsenic (As) were determined in sediments using computer controlled ICP-Atomic Emission Spectrometry according to EPA Method 2002 (EPA, 2007). The heavy metals (Pb, Cd, As) were determined in water using an Atomic Absorption Spectrophotometer (Varian SAA Pb). While determination of mercury (Hg) was determined by Atomic Absorption Spectrophotometer (Shimadzu AA 660) as a standard procedure by APHA (1992). All the measurements were carried out in triplicate.

Water samples were collected at each site for the laboratory analysis of total suspended matters (MES), which was analyzed as follows; Whatman number 1 glass-fiber filter disks (GF/C, millipore 0.45µm) were dried at 450-500 °C cooled in desiccators and weighed following the AFNOR method T90-105. A well-mixed sample of water was vacuum-filtered through the weighed filter paper and the filter was then removed and dried at 450-500 °C, after which it was cooled in desiccators and weighed. Total suspended matters analysis was performed in triplicate. The MES (mgL-1) was calculated according to the method of Aminot and Chaussepied *(*1983) as follow: MES = [P2-P1]/ V, with P1 (mg) weight of the filter paper before filtration (mg); P2 (mg) weight of the filter paper after filtration (mg); V sample volume (mL). The physico-chemical parameters such as pH, dissolved oxygen, salinity, conductivity and temperature were measured *in situ* with a multi-parameter (YSI 6920). The transparency was determined according to Secchi method.

Data analysis

A one-way Analysis of variance (ANOVA) was used to test the difference in concentrations of heavy metals in the water and the sediments. Differences in means values were separated using Duncan Multiple Range Test (DMRT) of variance to determine the variations due to sampling errors. Pearson correlation coefficient was applied to evaluate the relationship between heavy metals and physico-chemical parameters. Differences were considered significant at p values <0.05.

The seasonal and average water-sediment exchange factor (CE) for each heavy metal was calculated according to IRSN (2004): $CE = \frac{Cw}{Cs}$

With the heavy metal level in water (Cw) and sediments (Cs)

The contamination factor (CF) used for the evaluation of metal contamination of sediments (Hakanson et al., 1980).

$$CF = \frac{\text{Metal concentration in sediment}}{\text{reference content}}$$

The pollution level in heavy metal was calculated by the method based on pollution load index proposed by Thomlinson et al. (1980)

$$PLI = \sqrt[n]{FC1\ X\ FC2\ X \ldots\ldots X\ FCn}$$

With *n* number of metals analyzed; CF contamination factor.

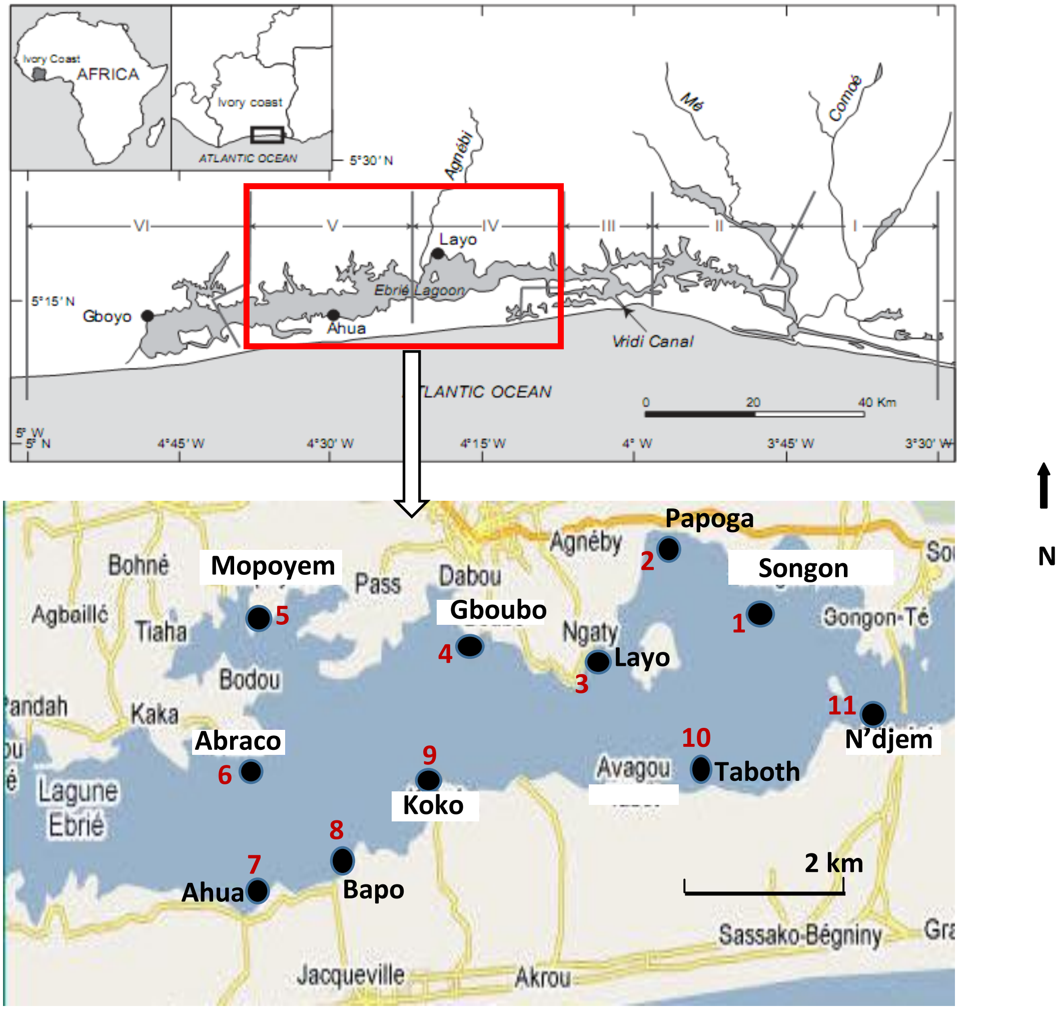

Figure 1: Location of sampling areas in the mainland area and maritime area ofEbrie Lagoon near the cities of Jacqueville and Dabou(Ivory Coast).Mainland area (1 Songon, 2 Papoga, 3 Layo, 4 Gboubo, 5 Mopoyem, 6 Abraco), maritime area (7 Ahua, 8 Bapo, 9 Koko, 10 Taboth,11 N'djem).

RESULTS

Quality parameters

The results of water quality in mainland area showed that temperature ranged from 28.04± 1.51 to 28.04 ± 1.51 °C, pH from 6.92 ± 0.62 to 7.27 ± 0.6, dissolved oxygen from 5.94 ± 1. 50 to 6.33 ± 2.81 mg/L, salinity from 1.54 ± 1.03 to 3.77 ± 2.53 ‰, conductivity from 3075.10 ± 1973.38 to 6598.25 ± 5058.35 mS/cm, transparency from 0.99 ± 0,36 to 1.20 ± 0.70 m, and suspended matters from 12.78 ± 7.64 to 15.41 ± 9.22 (Table 1). In the maritime area, seasonal water quality parameters show that temperature ranged from 28.23± 1.57 to 28.98± 1.79 °C, pH from 7.24± 0.30 to 7.32± 0.68, dissolved oxygen from 5.28±2.34 to 7.82± 2.46 mg/L, salinity from 2.60± 0.62 to 4.26± 2.12‰, conductivity from 5071.13 ± 990.40 to 8346± 4073.75 mS/cm, transparency from 1.32± 0.34 to 1.97± 0.73 m and suspended matter ranged from 10.34± 8.24 to 12.77±11.40 mg/L (Table 1).

Temperature, salinity and conductivity showed a significant difference ($p<0.05$) between seasons in mainland area. The highest values of these parameters were observed during the dry season while dissolved oxygen, salinity, conductivity and transparency were significantly higher ($p < 0.05$) in the water from maritime area during rainy season (Table 1).

Heavy metals

The seasonal mean water Hg levels ranged from 2.20± 0.96 µg/L in dry season to 2.27± 1.20 µg/L in swelling season in the mainland area and from 1.93±0.83 µg/L in rainy season to 2.13±0.91 µg/L in swelling season in the maritime area (Table 2). The mean water Pb concentrations in the season ranged from 5.20± 7.83 µg/L in swelling to 7.78± 7.07µg/L in rainy season in the mainland area and from 4.43±2.63 µg/L in swelling season to 6.65±5.84 µg/L in rainy season in the maritime area (Table 2). The seasonal mean water Cd concentrations in mainland and maritime areas ranged from 10.21±8.99 µg/L during the swelling season to 14.05±12.08 µg/L in rainy season and ranged from 9.14±9.58 µg/L in rainy season to 9.54±9.01 µg/L in dry season respectively (Table 2). The seasonal mean water As levels ranged from 4.99± 4.82 µg/L in swelling season to 8.17± 13.15 µg/L in dry season in mainland area; while the water from maritime area showed a significantly higher ($p < 0.05$) mean As concentration (16.95±29.82 µg/L) in swelling season compared to dry season (3.89±2.83 µg/L) (Table 2).

The annual mean water metal levels had no significant difference ($p > 0.05$) between mainland and maritime areas (Table 2). The seasonal mean sediments Hg, Pb, Cd and As levels in mainland and maritime areas are shown in Table 3. The order of seasonal concentrations of heavy metals in sediments in mainland and maritime areas was Pb_s>As_s>Hg_s>Cd_s. The seasonal mean sediments Hg levels ranged from 0.44± 0.19 mg/kg in dry season to 0.45± 0.24 mg/kg in swelling season in the mainland area and from 0.39±0.13 mg/kg in dry season to 0.42±0.18 mg/kg in swelling season in the maritime area. The mean sediments Pb concentrations in the season ranged from 23.26±0.012 mg/kg in dry season to 29.73±21.42 mg/kg in rainy season in the maritime area; while the sediments from mainland area showed a significantly higher ($p < 0.05$) mean Pb concentration (35.64± 21.93 mg/kg) in rainy season compared to swelling season (20.78± 17.78 mg/kg) (Table 3)

The seasonal mean sediments Cd concentrations in mainland and maritime areas ranged 0.20± 0.18 mg/kg during the swelling season to 0.28± 0.24 mg/kg in rainy season in mainland area; and ranged from 0.18±0.19 mg/kg in rainy season to 0.20±0.20 mg/kg in swelling season in maritime area. The seasonal mean sediments As levels ranged from 1.06± 0.70 mg/kg in the dry season to 1.22± 0.68 mg/kg in the rainy season in mainland area; and ranged from 1.01±0.59 mg/kg in the rainy season to 1.50±0.77 mg/kg in swelling season in maritime area. The annual mean sediments metal levels had no significant difference ($p > 0.05$) between mainland and maritime areas (Table 3).

The Pearson correlation between heavy metals and physico-chemical parameters showed a relationship between these parameters (Table 4 & 5). Arsenic (As) in water was strongly and negatively correlated to temperature, pH, salinity and conductivity in mainland area, while transparency and suspended matter were positively correlated respectively to Mercury (Hg) and Cadmium (Cd) in water. In maritime area, Arsenic (As) in water was significantly and negatively correlated to salinity and conductivity. In addition, Cadmium (Cd) and Lead (Pb) were negatively respectively correlated to pH and transparency.

The heavy metal mobility in water towards the sediments was characterized by the exchange factor (CE) water-sediments. The order of the exchange factor of metal was CE_{Cd}>CE_{Hg}> CE_{As}>CE_{Pb} in the both mainland and maritime areas (Table 6). Table 7 shows the contamination factor (CF) of each metal. The sediments of mainland area and maritime area were moderate contamination for Hg, Pb, Cd and As (1<CF<3), except the CF in maritime area indicates low contamination for Cd during seasons (CF=0.6-0.95 < 1). The pollution load index (PLI) in mainland area ranged from 1.47 to 1.84. The rainy season recorded the high PLI. In maritime area, the PLI ranged from 1.36 to 1.72. The swelling season recorded the high PLI. PLI value (PLI>1) indicates polluted sediment from mainland and maritime areas (Table 7).

Table 1: Annual and seasonal variations in physico-chemical parameters measured at mainland and maritime areas in the water of Ebrie lagoon from February 2014 to January 2015.

Water quality parameters	Areas	Annual	Seasons		
			Dry	Rainy	Swelling
Temperature (°C)	Mainland	28.84±0.86	29.74±1.70^{a}	28.72± 2.06^{b}	28.04± 1.51^{ab}
	Maritime	28.88±0.61	29.42±1.51	28.98± 1.79	28.23± 1.57
pH	Mainland	7.09±0.18^{2}	7.27±0.61	6.92± 0.62	7.08± 0.44
	Maritime	7.30±0.05^{1}	7.32±0.47	7.32± 0.68	7.24± 0.30
Dissolved oxygen (mgL^{-1})	Mainland	6.19±0.22	6.33±2.81	6.31± 2.32	5.94± 1.50
	Maritime	6.42±1.29	5.28±2.34^{a}	7.82± 2.46^{b}	6.16± 3.05^{ab}
Salinity (mgL^{-1})	Mainland	2.88±1.18	3.77±2.53^{a}	3.34± 2.62^{a}	1.54± 1.03^{b}
	Maritime	3.57±0.87	3.85±2.73^{ab}	4.26± 2.12$^{a'}$	2.60± 0.62^{b}
Conductiviy (mScm^{-1})	Mainland	5248.8±1900.7^{2}	6073.1±4518.4^{a}	6598.2± 5058.3^{a}	3075.1± 1973.3^{b}
	Maritime	6843.9±1654.1^{1}	7114.5±4524.5^{ab}	8346.0± 4073.7 ^{a}	5071.1± 990.4 ^{b}
Transparency (m)	Mainland	1.08±0.10^{2}	1.06±0.31	0.99± 0.36	1.0± 0.70
	Maritime	1,55±0.37^{1}	1.36±0.20^{b}	1.32± 0.34^{b}	1.97± 0.73^{a}
Suspended matter (mgL^{-1})	Mainland	13.80±1.41	12.78±7.64	15.41± 9.22	13.21± 11.50
	Maritime	11.74±1.25	12.77±11.40	10.34± 8.24	12.11± 8.88

Letters in the same row show differences among seasons ($p > 0.05$) a , b in the same row show significant differences between seasons ($p < 0.05$); same letters in the same row show no significant differences between seasons($p > 0.05$); 1& 2 in the same column show significant differences ($p < 0.05$) between areas.

Table 2: Annual and seasonal variations in heavy metals measured at mainland and maritime areas in the water of Ebrie lagoon from February 2014 to January 2015.

Heavy metals (µg/L)	Seasons				
	Areas	Annual	Dry	Rainy	Swelling
Mercury(Hg)	Mainland	2.24± 1.09	2.20± 0.96	2.27± 1.13	2.27± 1.20
	Maritime	2.01±0.80	1.97±0.66	1.93±0.83	2.13±0.91
Lead(Pb)	Mainland	5.21±3.847	6.03± 4.10[a]	6.58± 4.01[a]	3.01± 2.3[b]
	Maritime	5.04±4.427	4.44±2.60[a]	6.66±5.84[b]	4.03±3.09[a]
Cadmium(Cd)	Mainland	12.29±10.24	12.61±9.40	14.05±12.08	10.21±8.99
	Maritime	6.88±6.56	9.54±9.00[a]	4.22±2.36[b]	6. 90±5.65[b]
Arsenic (As)	Mainland	4.17±3.37	3.10±1.34	4.01± 1.63	5.41±5.26
	Maritime	4.31±2.661	3.89±2.83	3.58±2.09	5.45±2.73

Letters a and b in the same row show differences among seasons ($p > 0.05$).

Table 3: Annual and seasonal variations in heavy metals measured at mainland and maritime areas in the sediments of Ebrie lagoon from February 2014 to January 2015.

Heavy metals (mg/kg)	Seasons				
	Areas	Annual	Dry	Rainy	Swelling
Mercury(Hg)	Mainland	0.45± 0.22[1]	0.44± 0.19	0.45± 0.23	0.45± 0.24
	Maritime	0.40±0.16[2]	0.39±0.13	0.39±0.17	0.42±0.18
Lead(Pb)	Mainland	30.40±21.94	34.79± 23.31[a]	35.64±21.93[a]	20.78± 17.78[b]
	Maritime	32.07±24.39	22.41±12.94	32.87±22.88	40.93±31.22
Cadmium(Cd)	Mainland	0.25± 0.20[1]	0.25± 0.19	0.28± 0.24	0.20± 0.18
	Maritime	0.15±0.13[2]	0.19±0.18	0.12±0.08	0.15±0.12
Arsenic (As)	Mainland	1.13± 0.66	1.06± 0.70	1.22± 0.68	1.12± 0.63
	Maritime	1.21±0.75	1.10±0.80	1.01±0.59	1.54±0.73

Letters a and b in the same row show differences among seasons ($p > 0.05$); same letters in the same row show no significant differences between seasons ($p > 0.05$).

Table 4: Correlation between heavy metals and Physico-chemical parameters measured at mainland area in the water of Ebrie lagoon from February 2014 to January 2015.

	Hg	**Pb**	**Cd**	**As**	**T°**	**pH**	**O_2**	**Sal**	**Cdt**	**Trsp**	**MS**
Hg	1.00										
Pb	-0.35	1.00									
Cd	0.16	-0.12	1.00								
As	0.48	0.02	0.66*	1.00							
T°	-0.38	-0.27	-0.29	-0.64*	1.00						
pH	0.16	-0.59	-0.51	-0.64*	0.56	1.00					
O_2	0.23	0.21	-0.43	-0.08	0.15	0.33	1.00				
Sal	-0.33	-0.19	-0.47	-0.87*	0.56	0.77*	0.06	1.00			
Cdt	-0.34	-0.16	-0.47	-0.84*	0.58	0.76*	0.12	0.99*	1.00		
Trsp	0.60*	-0.56	-0.00	0.47	-0.46	0.17	0.09	-0.32	-0.33	1.00	
MES	-0.14	-0.00	0.69*	0.40	-0.02	-0.53	-0.49	-0.38	-0.37	-0.19	1.00

Significant correlations are indicated by * at p <0.05. Hg mercury ; Pb lead ;Cd Cadmium ; As Arsenic ; T° Température ;pH Hydrogen Potential;O_2 dissolved Oxygen ;Sal Salinity ;Cdt Conductivity ; Trsp Transparency ; MES Suspended matter.

Table 5: Correlation between heavy metals and Physico-chemical parameters measured at maritime area in the water of Ebrie lagoon from February 2014 to January 2015.

	Hg	**Pb**	**Cd**	**As**	**T°**	**pH**	**O_2**	**Sal**	**Cdt**	**Trsp**	**MES**
Hg	1.00										
Pb	0.29	1.00									
Cd	-0.28	0.43	1.00								
As	-0.05	-0.56	-0.29	1.00							
T°	0.38	0.46	-0.38	-0.54	1.00						
pH	0.09	0.04	-0.67*	-0.15	0.61	1.00					
O_2	-0.03	0.27	-0.28	-0.15	0.17	0.40	1.00				
Sal	0.15	0.34	-0.22	-0.63*	0.63	0.72*	0.18	1,00			
Cdt	0.22	0.34	-0.23	-0.61*	0.59	0.61*	0.26	0.96*	1.00		
Trsp	-0.23	-0.72*	-0.41	0.06	-0.00	0.24	0.01	0.02	-0.00	1.00	
MES	-0.47	-0.07	-0.19	0.27	-0.15	-0.16	-0.07	-0.17	-0.16	-0.14	1.00

*Significant correlations are indicated by * at p <0.05. Hg mercury ; Pb lead ;Cd Cadmium ; As Arsenic ; T° Température ;pH Hydrogen potential;O_2 Dissolved oxygen ;Sal Salinity ;Cdt Conductivity ; Trsp Transparency ; MES Suspended matter.*

Table 6: Seasonal and annual exchange factor of water-sediment in mainland and maritime areas of Ebrie lagoon from February 2014 to January 2015.

			Saisons		
Heavy metals	**Areas**	**Annual**	**Dry**	**Rainy**	**Swelling**
Hg	Mainland	4.97	5.00	5.04	5.04
	Maritime	5.03	5.05	4.95	5.07
Pb	Mainland	0.17	0.17	0.18	0.14
	Maritime	0.16	0.20	0.20	0.10
Cd	Mainland	49.16	50.44	50.18	51.05
	Maritime	44.26	50.21	35.17	46.00
As	Mainland	3.69	2.92	3.28	4.43
	Maritime	3.54	3.54	3.54	3.54

Table 7: Seasonal contamination factor (CF) and pollution load index (PLI) of sediments in mainland and Maritime areas of Ebrie lagoon from February 2014 to January 2015.

		Mainland area		Maritime area	
Saisons	**Heavy metals**	**CF**	**PLI**	**CF**	**PLI**
Dry	Hg	1.76	**1.73**	1.56	**1.42**
	Pb	3.05		1.96	
	Cd	1.25		0.95	
	As	1.34		1.39	
Rainy	Hg	1.80	**1.87**	1.56	**1.36**
	Pb	3.13		2.86	
	Cd	1.40		0.6	
	As	1.54		1.28	
Swelling	Hg	1.80	**1.47**	1.68	**1.72**
	Pb	1.82		3.60	
	Cd	1.00		0.75	
	As	1.42		1.94	

DISCUSSION

This study revealed that seasonal temperature was higher (29.74±1.70 °C and 29.42±1.51 °C) in both mainland and maritime areas respectively in the dry season. These highest temperatures could be attributed to the air warming the on one hand and to the low shallow depth of the areas on the other hand. The water pH values of these areas are alkaline with annual pH-values (7.09±0.18) and (7.30±0.05) respectively in mainland and maritime areas. These pH levels were appropriate for aquatic life (Yao et al., 2009). Mean values of dissolved oxygen varied slightly between seasons and in both areas. This agrees with the report of Sylla (2010) in the same areas (sectors VI and V of Ebrie lagoon) that dissolved oxygen in water may be due to the abundance of phytoplankton that increases photosynthetic activities leading to production of large amount of dissolved oxygen.

Salinity and conductivity levels are highest in the maritime area during dry season. These higher levels salinity and conductivity of maritime water might be due to the seawater inflow into the lagoon during the dry season (Adama et al., 2013). In contrast, the lower values of salinity and conductivity measured in mainland area in swelling season could be attributed to the Agneby freshwater. Similarly, water transparency in mainland area suggests that run-off from mainland area during the rainy and swelling seasons and agricultural activities are major sources of suspended matters in the lagoon which increase the plankton abundance (Koffi et al., 2014).

Generally, the results showed no seasonal significant differences in the heavy metal concentrations in water in both mainland and maritime areas, except arsenic levels in maritime area. The means concentrations of Cd (10.21- 14.05 µg/L) and Pb (5.20- 7.78 µg/L) were lower than the values (Cd= 30- 47 µg/L and Pb = 0- 96 µg/L) reported by Inza et al. (2015) in the Ebrie lagoon. These low concentrations of metals in the mainland and maritime areas near Jacqueville and Dabou might be due to less agro-chemical usage around the study areas and less industrial activities which are the major sources of heavy metal contamination in aquatic environments (Banjo et al., 2010). Although Hg and Cd levels in water from both areas were higher than the safe limit for human consumption (Hg = 1,00 mg/L; Cd=5,00 mg/L) as set by WHO (2001). Generally, sediments in this study accumulated metals (Hg, Pb, Cd and As) in higher levels than water and this shows that sediments act as the most important reservoir or sink for metals in the aquatic environment (Abdel-Baki et al., 2011**).**

Metal concentrations in the sediments of the study areas were no exceed the standard concentration levels (Pb=100 mg/kg; Cd=1.2 mg/kg; As= 25 mg/kg; Hg=0.04 mg/kg) as recommended by INERIS (2010) except Hg level. This highest Hg concentration in the sediments could be a chronic poisoning of the aquatic organisms.

This study clearly revealed that there is a strong relationship between metal levels and water quality parameters in both mainland and maritime areas. These relationships were controlled by that of the different factors in the aquatic environments, types and level of water pollution (Chouti et al., 2010) or the origin of water discharge (El Morhit, 2008; Kambiré, 2014) or the source of pollution such as human activities including banana plantations, oil palm and rubber trees in the study area (Yao et al., 2007; Atta et al., 2014).

The values of exchange factor water-sediment of all metals (except Pb with CE< 1) were higher showing greater mobility of Hg, Cd, As in water toward the sediments. The accumulation of metals from the overlying water to sediments is dependent on a number of external environmental factors such as pH, conductivity or salinity. In contrast, the lower mobility of Pb can result from its low solubilty, high absorption and retention coefficient by sediment (Casaas, 2005; Youssao et al., 2011). The sediments of mainland area and maritime area were moderate contamination for Hg, Pb, Cd and As (1<CF<3), except the CF in maritime area which indicates low contamination for Cd during seasons (CF=0.6-0.95 < 1). In contrast, Wognin et al. (2017) were found in the estuarine part of the Ebrie lagoon the hightly values of CF during the rainy and swelling seasons. Indeed, in this part of Ebrie lagoon, the discharge of wastewater and freshwater are very important. Generally, the PLI>1 indicates polluted sediment from mainland and maritime areas during seasons. Therefore, the sediments contamination could be a chronic poisoning of the aquatic organisms.

Conclusion

This study revealed that the mean concentration of all metals was highest in water and sediments of mainland are compared to maritime area. This highest accumulation in water and sediments may be as a result of human activities practiced (plantations of banana and coconut, fishing activities, industrial activities). The results revealed that the values of mercury and cadmium in areas were higher than the allowed value recommended and the sediments were heavily contaminated with mercury. The high concentration level could be a chronic poisoning of the aquatic organism.

COMPETING INTERESTS

The authors declare that they have no competing interests in relation to this article.

AUTHORS' CONTRIBUTIONS

NMK supervised the entire work. SC contributed to the collection of field data, analyzed the samples and contributed to writing the manuscript. BCA collected the field data, and contributed to writing. BGG contributed to the drafting the manuscript.

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